IoT Assisted MQTT for segregation and monitoring of waste for smart cities

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KEYWORDS	ABSTRACT
Internet of Things (IoT), MQTT protocol, Smart waste management, Waste segregation, Ultrasonic sensor, Moisture sensor, Smart cities	*Rapid urbanization has increased the complexity of waste management and monitoring in smart cities, demanding intelligent and automated solutions. This paper presents an IoT-assisted MQTT-based system for real-time waste segregation and monitoring aimed at improving urban cleanliness and operational efficiency. The proposed system employs ultrasonic sensors to continuously monitor waste bin fill levels, enabling timely waste collection and preventing overflow. A moisture sensor is used to perform basic segregation by distinguishing between wet and dry waste at the source. Sensor data are acquired and processed using an ESP32 microcontroller and transmitted to a cloud platform through the lightweight MQTT protocol, ensuring reliable and low-latency communication. The system supports real-time visualization through a mobile application and provides instant alerts via a buzzer and display unit when predefined thresholds are exceeded. By enabling continuous monitoring, efficient segregation, and remote supervision, the proposed solution reduces manual intervention, optimizes waste collection processes, and supports sustainable urban development. The system demonstrates a scalable and cost-effective approach suitable for deployment in smart city environments.*

I. INTRODUCTION

Rapid urbanization and population growth have significantly increased the complexity of municipal solid waste management, posing serious challenges to urban hygiene, environmental sustainability, and public health. Traditional waste collection methods rely heavily on fixed schedules and manual monitoring, often resulting in inefficient resource utilization, overflowing bins, and delayed responses to hazardous conditions [1][3]. Studies have shown that improper waste handling adversely impacts human health and environmental quality, highlighting the need for smarter and more sustainable waste management strategies [4].

In recent years, the concept of smart cities has

emerged as a promising solution to address urban infrastructure challenges by integrating information and communication technologies with city services [5][6]. Waste management has become a critical component of smart city initiatives, particularly in developing countries where rapid urban expansion strains existing systems [7][15]. Internet of Things (IoT) technologies enable real-time sensing, data transmission, and automated decision-making, making them well-suited for intelligent waste monitoring applications [9][10].

Several researchers have explored IoT-based smart waste management systems utilizing sensors to monitor bin fill levels and transmit data to centralized platforms for optimized collection scheduling [11]. Ultrasonic sensors have been widely adopted for non-contact measurement of waste levels, while cloud-based dashboards allow municipal authorities to visualize and manage waste data remotely. Recent advancements have also emphasized the importance of waste segregation at the source to improve recycling efficiency and reduce landfill burden [8][12]. Moisture-based sensing techniques provide a simple yet effective approach to distinguish between wet and dry waste, facilitating primary-level segregation.

Communication protocols play a vital role in the reliability and scalability of IoT systems. Lightweight messaging protocols such as MQTT have gained prominence due to their low bandwidth consumption, minimal latency, and suitability for resource-constrained devices [14]. MQTT-based architectures enhance real-time data exchange between sensor nodes and cloud platforms, making them ideal for large-scale smart city deployments. Furthermore, integrating mobile applications and alert mechanisms improves system responsiveness and enables timely interventions [13].

Despite the progress in smart waste management research, many existing solutions focus solely on monitoring without addressing efficient communication, real-time alerts, and scalable segregation mechanisms. This paper proposes an IoT-assisted MQTT-based waste segregation and monitoring system designed for smart city environments. The system integrates ultrasonic and moisture sensors with an ESP32 microcontroller and employs the MQTT protocol for efficient data transmission. Real-time visualization and alert mechanisms support informed decision-making and improved operational efficiency. The proposed approach aims to enhance sustainability, reduce manual intervention, and contribute to data-driven urban waste management.
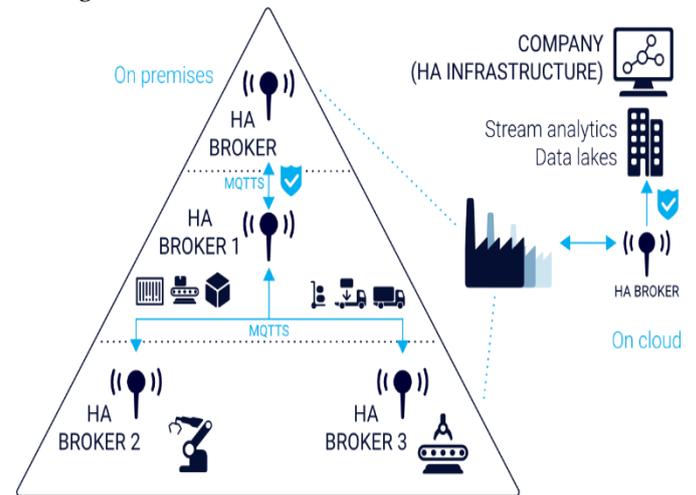

Figure 1 Overview of the IoT-assisted MQTT-based waste segregation and monitoring system

II. RELATED WORK

Waste management has been an active research area for several decades, with early studies focusing on conventional collection practices, disposal methods, and environmental implications. Bilitewski et al. [1] presented one of the foundational contributions to waste management, discussing treatment technologies, logistics planning, and regulatory frameworks. Reno [2] later explored anthropological and socio-economic perspectives of waste generation, emphasizing the complex and global nature of urban waste challenges. Global assessments conducted by Hoornweg and Bhada-Tata [3] highlighted the rapid growth of municipal solid waste worldwide and stressed the urgent need for sustainable and technology-driven management approaches.

The health and environmental consequences of improper waste handling have been widely documented. Giusti [4] reviewed waste management practices and their associated public health risks, identifying hazardous waste exposure as a significant concern in densely populated urban regions. With the emergence of smart cities, researchers began integrating advanced technologies to improve waste management efficiency. Esmaeilian et al. [5] provided a comprehensive review of waste management systems in smart and sustainable cities, proposing integrated frameworks combining sensing technologies, data analytics, and policy measures. Similarly, Mingaleva et al. [6] analyzed green

and smart city initiatives, demonstrating how digital infrastructure can enhance waste management performance through structured planning and technological adoption.

The integration of Internet of Things (IoT) technologies has significantly transformed waste monitoring systems by enabling real-time data acquisition and automation. Malapur and Pattanshetti [9] proposed an IoT-based waste monitoring system that uses sensors to detect bin fill levels and transmit information to a centralized server for optimized collection scheduling. Shyam et al. [10] introduced a smart waste management model employing IoT to enhance collection efficiency while reducing operational costs. Ali et al. [11] further advanced this approach by developing a smart waste bin monitoring system integrated with municipal solid waste management platforms, demonstrating improved responsiveness and transparency through real-time monitoring.

Recent research has shifted toward sustainability and intelligent optimization in waste management systems. Salehi-Amiri et al. [8] proposed a two-stage IoT-based waste management framework aimed at sustainability and operational optimization. Mohamad et al. [12] focused on electronic waste management, proposing IoT-based guidelines to address environmental challenges associated with e-waste disposal. Nižetić et al. [13] emphasized the broader role of smart technologies in enhancing energy efficiency and environmental performance within smart city ecosystems.

Advanced systems integrating IoT with machine learning and data analytics have also been investigated. Khan et al. [14] proposed a hybrid IoT and machine learning-based waste management model designed to improve predictive capabilities and decision-making accuracy. However, such approaches often introduce higher computational complexity and increased deployment costs. Fidje et al. [15] examined the challenges of implementing smart waste management systems in developing countries, underlining the importance of cost-effective, scalable, and easy-to-deploy solutions.

Although existing studies demonstrate the benefits of IoT-enabled waste monitoring, many solutions primarily focus on bin-level fill monitoring without incorporating efficient communication protocols or basic waste segregation mechanisms. Furthermore, limited attention

has been given to lightweight messaging protocols suitable for large-scale smart city deployments. To overcome these limitations, the proposed work introduces an IoT-assisted MQTT-based framework that integrates waste segregation and real-time monitoring, offering a scalable, efficient, and sustainable solution for smart city waste management.

III. PROPOSED SYSTEM

The architecture of the proposed IoT-assisted MQTT-based waste segregation and monitoring system is structured to ensure real-time data acquisition, efficient communication, and remote monitoring. The overall design follows a layered architecture consisting of four main components: the sensing layer, processing layer, communication layer, and application layer.

1. Sensing Layer

The sensing layer is responsible for real-time data acquisition from the waste bin. It includes:

Ultrasonic Sensor – Measures the distance between the sensor and the waste surface to calculate the fill level of the bin. This non-contact method ensures durability and hygiene.

Moisture Sensor – Detects the presence of moisture in waste to classify it as wet or dry, enabling primary-level segregation at the source.

These sensors continuously monitor bin conditions and transmit raw data to the processing unit.

2. Processing Layer

The processing layer is implemented using an ESP32 microcontroller, which acts as the central control unit of the system. The ESP32 performs the following functions:

Collects sensor readings from ultrasonic and moisture sensors

Applies threshold-based logic for overflow detection and waste classification

Formats processed data for communication

Triggers local alerts when necessary

With built-in Wi-Fi capability, low power consumption, and sufficient computational resources, the ESP32 is highly suitable for smart city IoT deployments.

3. Communication Layer

The communication layer utilizes the Message Queuing Telemetry Transport (MQTT) protocol for data

transmission. MQTT operates on a lightweight publish–subscribe model, making it ideal for resource-constrained IoT devices.

In this system:

The ESP32 publishes bin status and segregation data to predefined MQTT topics.

A cloud-based MQTT broker manages message distribution.

Subscribers (mobile app/dashboard) receive updates in real time.

The use of MQTT ensures:

Low bandwidth consumption

Minimal latency

High scalability for large-scale smart city implementation

4. Application Layer

The application layer provides user interaction and visualization. It consists of:

Mobile Application Dashboard – Subscribes to MQTT topics and displays real-time bin fill level, waste type (wet/dry), and alert notifications.

Local Alert System – Includes an LCD display and buzzer to generate alerts when predefined thresholds (e.g., bin overflow) are exceeded.

This multi-layer architecture ensures:

Timely decision-making

Reduced manual monitoring

Improved collection scheduling

Enhanced operational efficiency

Overall, the layered design enables seamless integration of sensing, processing, communication, and visualization components, making the system scalable, reliable, and suitable for smart city waste management environments..
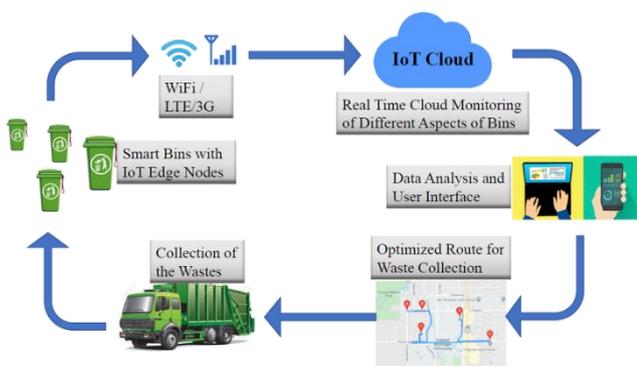

Figure 2 System architecture of the IoT-assisted MQTT-based waste segregation and monitoring system.

IV. METHODOLOGY

The proposed system adopts a modular and layered methodology to achieve real-time waste segregation and monitoring using IoT technology and MQTT communication. The workflow integrates sensor-based data acquisition, local edge processing using a microcontroller, wireless transmission via MQTT, and real-time visualization with alert mechanisms. The methodology is structured to ensure scalability, low latency, reliability, and energy efficiency for smart city deployment.

Algorithm 1 Waste Level Monitoring Algorithm

1: Initialize ultrasonic sensor
2: Set bin_height and threshold_level
3: **while** system is active **do**
4:     Trigger ultrasonic pulse
5:     Measure echo time
6:     Calculate distance using speed of sound
7:     Compute fill_level = bin_height − distance
8:     **if** fill_level ≥ threshold_level **then**
9:         Generate overflow alert
10:    **end if**
11:    Publish fill_level data via MQTT
12: **end while**

Algorithm 2 Waste Segregation Algorithm

1: Initialize moisture sensor
2: Set moisture_threshold
3: **while** system is active **do**
4:     Read moisture value
5:     **if** moisture value > moisture_threshold **then**
6:         Classify waste as **Wet**
7:     **else**
8:         Classify waste as **Dry**
9:     **end if**
10:    Publish waste type via MQTT
11: **end while**

Algorithm 3 MQTT Communication Algorithm

1: Initialize Wi-Fi connection
2: Connect ESP32 to MQTT broker
3: Define MQTT topics for bin level and waste type
4: **while** connected to broker **do**
5:     Publish sensor data to respective topics
6:     Wait for acknowledgment
7:     **if** connection lost **then**
8:         Reconnect to broker
9:     **end if**
10: **end while**

1. System Workflow

The system operates continuously to monitor waste bin conditions. The ultrasonic sensor measures the fill level by calculating the distance between the sensor and

the waste surface. Simultaneously, the moisture sensor determines whether the waste is wet or dry.

The ESP32 microcontroller processes the collected data using predefined thresholds and classification logic. The processed information is then transmitted to a cloud-based MQTT broker. A mobile application subscribes to relevant MQTT topics and displays real-time bin status. If predefined limits are exceeded (e.g., overflow), alert mechanisms are triggered both locally and remotely.

2. Waste Level Monitoring Algorithm

Ultrasonic sensing is used to determine bin occupancy. The distance is calculated using the time-of-flight principle of sound waves.

This algorithm ensures continuous monitoring and early detection of bin overflow.

3. Waste Segregation Algorithm

Moisture sensing is employed to classify waste into wet or dry categories.

Algorithm Steps

Initialize moisture sensor

Set moisture threshold value

Read moisture level

Compare with threshold

Classify waste

Publish waste type via MQTT

This primary-level segregation improves recycling efficiency and reduces landfill burden.

4. MQTT Communication Algorithm

The system uses MQTT's publish–subscribe model for lightweight and efficient data exchange.

If connection is lost → Attempt automatic reconnection

This ensures reliable, scalable, and low-bandwidth communication suitable for large-scale smart city deployments.

5. Alert Generation Algorithm

Alerts are generated when threshold conditions are met. This dual-level alert mechanism ensures both local and remote awareness, enabling quick response and optimized collection scheduling.

Methodology Summary

The modular and layered design ensures that the system is scalable, energy-efficient, and suitable for deployment in smart city environments.

V. RESULTS AND DISCUSSIONS

The proposed IoT-assisted MQTT-based waste segregation and monitoring system was implemented and experimentally validated using a functional hardware prototype integrated with real-time IoT communication and visualization. The results demonstrate effective waste level monitoring, basic segregation capability, and reliable alert generation suitable for smart city applications.
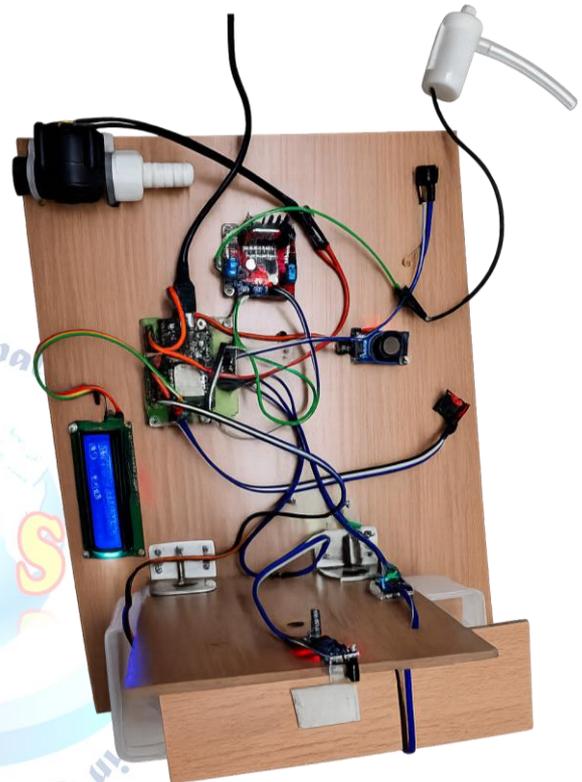

Figure 3 Developed hardware prototype of the IoT-assisted waste segregation and monitoring system

The hardware prototype consists of an ESP32 microcontroller interfaced with:

An ultrasonic sensor for waste level detection

A moisture sensor for waste segregation

An LCD display for local visualization

A buzzer for alert indication

The ultrasonic sensor accurately measured the fill level under varying load conditions. The system successfully detected near-full and overflow states based on predefined thresholds. Experimental observations showed consistent measurement performance with minimal fluctuation.

Figure 4 IoT dashboard showing real-time waste level and segregation status using MQTT

The moisture sensor effectively distinguished between wet and dry waste, enabling primary-level segregation at the source. This contributes to improved recycling efficiency and reduced landfill burden.

During continuous testing, the ESP32 demonstrated stable data acquisition and processing with negligible delay. Local alerts were triggered immediately when threshold levels were exceeded, confirming real-time operational capability.

IoT and MQTT Communication Results

The system utilized the MQTT protocol for transmitting sensor data to a cloud-based platform. Real-time monitoring dashboards displayed:

Waste bin fill percentage

Wet/Dry waste classification

Alert notifications

The MQTT publish–subscribe model ensured:

Low latency communication

Reliable message delivery

Efficient bandwidth utilization

Scalability for multiple bins

Compared to conventional HTTP-based communication, MQTT significantly reduced network overhead and improved response time, making the system suitable for large-scale smart city deployments.

Alert and Visualization Performance

The alert mechanism operated in both local and remote modes:

Local Alerts:

Buzzer activation

LCD warning display

Remote Alerts:

Mobile dashboard notification

Real-time overflow indication

When the bin level exceeded the predefined threshold, alerts were triggered instantly. The synchronized local and remote notifications ensured immediate awareness for on-site workers and municipal authorities.

VI. CONCLUSION

This work presented an IoT-assisted MQTT-based waste segregation and monitoring system tailored for smart city environments. The system integrates ultrasonic and moisture sensors with an ESP32 microcontroller to enable:

Real-time waste level monitoring

Basic wet/dry waste segregation

Efficient MQTT-based communication

Dual-mode alert mechanisms

Experimental validation through the hardware prototype and IoT dashboard demonstrated reliable sensor performance, stable communication, and effective alert generation.

Compared to conventional waste management systems, the proposed approach offers:

Improved operational efficiency

Reduced manual intervention

Scalable architecture

Cost-effective implementation

Future work will focus on:

Machine learning-based advanced waste classification

GPS-based route optimization for collection vehicles

Large-scale field deployment

Energy optimization strategies

Integration of additional environmental sensors

The proposed framework establishes a scalable foundation for intelligent, data-driven waste management in smart cities and can be extended to support comprehensive urban sustainability initiatives

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

REFERENCES

[1] B. Bilitewski, G. H¨ardt le, and K. Marek, Waste Management. Springer Science & Business Media, 1996.

[2] J. Reno, "Waste and waste management," Annual Review of Anthropol- ogy, vol. 44, pp. 557–572, 2015.

[3] D. Hoornweg and P. Bhada-Tata, "What a waste: A global review of solid waste management," World Bank Report, 2012.

[4] L. Giusti, "A review of waste management practices and their impact on human health," Waste Management, vol. 29, no. 8, pp. 2227–2239, 2009.

[5] B. Esmaeilian, B. Wang, K. Lewis, F. Duarte, C. Ratti, and S. Behdad, "The future of waste management in smart and sustainable cities: A review and concept paper," Waste Management, vol. 81, pp. 177–195, 2018.

[6] Z. Mingaleva, N. Vukovic, I. Volkova, and T. Salimova, "Waste manage- ment in green and smart cities: A case study of Russia," Sustainability, vol. 12, no. 1, p. 94, 2019.

[7] V. R. S. Cheela, V. P. Ranjan, S. Goel, M. John, and B. Dubey, "Pathways to sustainable waste management in Indian smart cities," Journal of Urban Management, vol. 10, no. 4, pp. 419–429, 2021.

[8] A. Salehi-Amiri, N. Akbapour, M. Hajiaghaei-Keshteli, Y. Gajpal, and A. Jabbarzadeh, "Designing an effective two-stage, sustainable, and IoT- based waste management system," Renewable and Sustainable Energy Reviews, vol. 157, p. 112031, 2022.

[9] B. S. Malapur and V. R. Pattanshetti, "IoT based waste management: An application to smart city," in Proc. Int. Conf. Energy, Communication, Data Analytics and Soft Computing (ICECDS), IEEE, 2017, pp. 2476– 2486.

[10] G. K. Shyam, S. S. Manvi, and P. Bharti, "Smart waste management using Internet of Things (IoT)," in Proc. 2nd Int. Conf. Computing and Communication Technologies (ICCCT), IEEE, 2017, pp. 199–203.

[11] T. Ali, M. Irfan, A. S. Alwadie, and A. Glowacz, "IoT-based smart waste bin monitoring and municipal solid waste management system for smart cities," Arabian Journal for Science and Engineering, vol. 45, pp. 10185–10198, 2020.

[12] R. M. Mohamad et al., "The development of sustainable IoT e-waste management guideline for households," Chemosphere, vol. 303, p. 134767, 2022.

[13] S. Niˇzeti´c, N. Djilali, A. Papadopoulos, and J. J. P. C. Rodrigues, "Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management," Journal of Cleaner Production, vol. 231, pp. 565–591, 2019.

[14] R. Khan et al., "Machine learning and IoT-based waste management model," Computational Intelligence and Neuroscience, 2021.

[15] E. Fidje, M. Haddara, and M. Langseth, "Sustainable smart waste management adoption challenges in developing countries," Procedia Computer Science, vol. 219, pp. 905–914, 2023.

[16] S. V. Akram et al., "Implementation of digitalized technologies for fash- ion industry 4.0: Opportunities and challenges," Scientific Programming, 2022.

[17] A. Rokade et al., "Intelligent data analytics framework for precision farming using IoT and regressor machine learning algorithms," Applied Sciences, vol. 12, no. 19, p. 9992, 2022.

[18] G. P. K. Marwah et al., "An improved machine learning model with hybrid technique in VANET for robust communication," Mathematics, vol. 10, no. 21, p. 4030, 2022.

[19] S. Kimothi et al., "Spatio-temporal fluctuations analysis of land surface temperature using remote sensing data and multifractal technique," Sustainable Energy Technologies and Assessments, vol. 55, p. 102956, 2023.